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# NATIONAL BUREAU OF STANDARDS REPORT



8TH MEETING OF C.I.B. COMMISSION W.14

FIRE RESEARCH STATION, BOREHAM WOOD, ENGLAND

23–27 SEPTEMBER 1968

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

## NATIONAL BUREAU OF STANDARDS

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The Bureau comprises the Institute for Basic Standards, the Institute for Materials Research, the Institute for Applied Technology, and the Center for Radiation Research.

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[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D. C. 20234.
[2] Located at Boulder, Colorado 80302.
[3] Located at 5285 Port Royal Road, Springfield, Virginia 22151.

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ABSTRACT

A summary is presented of the proceedings at the 8th meeting of the Working Group on Fire of the Conseil International du Batiment (CIB/CTF) held at the British Fire Research Station, 23 to 27 September 1968. The activities and progress of working groups on Fire Endurance, Smoke and Gases, and Fires in Single Compartments are reported.

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## 1. GENERAL INFORMATION

The previous (7th) meeting of CIB Commission W.14 - Working Group on Fire - met two years earlier in Copenhagen and details of that meeting are given in NBS Report No. 9336 [1]. The 8th meeting was convened on 23 September 1968 at the Fire Research Station, Boreham Wood, England. The list of delegates from 12 countries is included as Appendix A. The program arranged for the delegates is shown in Appendix B. The formal meeting started with a welcome from Mr. Lawson, Director of the Fire Research Station, who had graciously hosted a buffet supper at his home the previous evening. Mr. Lawson was elected Chairman for the week's proceedings. After acceptance of the official report of the 7th meeting, three discussion groups were formed. As in previous meetings, delegates were free to join one of the three following groups to discuss progress: Group 1 - Fire Endurance; Group 2 - Spread of Smoke and Toxic Gases; and Group 3 - Fires in Single Compartments. Informal discussions within groups continued through the day and a short report was presented to the reassembled delegates the following morning. The following information is based upon the summary report as presented by the Secretaries of the three groups: Group 1 - Mr. Malhotra, Fire Research Station; Group 2 - Dr. Robertson, NBS; Group 3 - Mr. Heselden, Fire Research Station; and from additional notes by Dr. Robertson (Group 2) and by Mr. Gross (Group 3).

# 2. REPORT OF GROUPS

## 2.1 Group 1 (Fire Endurance) and Discussion

There was a discussion on the correlation of furnaces. Mr. Stanke (BAM) presented the report. Participating laboratories were three from Germany (BAM, Dortmund, BASF), Holland (TNO), France (CSTB) and England (JFRO). A great variability in the furnace temperature was noted particularly in the first ten minutes. In a test of 90-minute duration the time to a critical unexposed surface temperature differed by as much as 23 minutes. The differences in the fuel used, in the methods of measurement, and in the furnace time-temperature curve did not explain the differences in the test data. It was concluded that correlation does not exist between furnaces at the various laboratories. For future studies it was suggested that a 60 x 60 cm steel panel be mounted in the wall of the furnace. Germany offered to provide the panels and England to provide the thermocouples. Participating laboratories included four from Germany; one each from France, Holland, England, Australia, and Belgium. In the discussion that followed the presentation of the Group 1 report, the following points were raised. The thermocouple required by ISO 1060 appeared to be adequately specified according to Prof. Herpol. In Mr. Keough's opinion a force applied to the thermocouple pad to maintain uniform tension might be an advantage. Mr. Becker remarked that furnaces which have the lowest furnace temperatures appeared to have the highest surface temperatures. Mr. Bellisson stated that if thermocouples were mounted throughout the thickness of the steel plates the temperature at the surface could be obtained by extrapolation, and in addition a 3 mm hole recessed in the steel could be used for direct measurement of its surface temperature. Prof. Herpol suggested the original laminated specimen would be better from the heat transfer standpoint. The original laminated test piece was constructed of four sheets of 10 mm thick asbestos cement board with thermocouples located between the laminations. Mr. Stanke remarked that slight indentations were made to receive copper discs and the sheets were screwed together every 10 cm without adhesive to give good thermal contact. However, the absence of air spaces could not be totally assured. Mr. Stanke agreed to prepare a report with the cooperation of Mr. Witteveen on the tests performed.

## 2.2 Group 2 (Smoke and Gases) and Discussion

Dr. Robertson presented a comprehensive summary of the discussions in Group 2. These were divided into six principle categories: (1) mechanism of smoke development; (2) test methods for measuring smoke with exploration of the fire exposure conditions; (3) smoke movement

in buildings; (4) toxic products of smoke; (5) "smoke load" in buildings; and (6) smoke tolerance limits. It was reported that Dr. Saito from Japan has performed some fundamental smoke studies and these were reported in CIB Report 68/36. Also reported was the work of Dr. Rumberg from Germany on the moving furnace test method. Prof. Herpol noted that the appropriate exposure conditions were very important. Mr. McGuire pointed out the importance of air movement in buildings and mentioned that smoke could pass through concrete elevator shafts. He also noted that a pressure difference of about two inches of water between the interior and exterior was measured (in winter). Normally the neutral zone is found somewhere near the mid-height of the building. Also, a vent area equal to 3% of the building area at the top of the elevator shaft is generally adequate up to a height of 10 stories, but that 30 to 40% vent area is required for buildings of 40 stories and higher. It was suggested that a diaphragm separating the building into two vertical sections and thereby isolating fire and smoke to the section of fire origin would be beneficial and would permit the passage of occupants through doors in the diaphragm. Col. Cabret remarked that studies were made in two corridors of 20 meter length in a six- or seven-story building built for experimental studies. A sasse (vestibule) with a low level intake and a high level exhaust was arranged with ducts and dampers and mechanical pumps to provide pressure or suction. Buildings are built in France with both natural and mechanical methods for handling smoke. Mr. Butcher mentioned that the pressurization of stairwells to 0.1 to 0.2 in of water was found to be adequate up to five stories. He mentioned that improved fire performance of doors was desirable. Also mentioned was the use of computers to predict and analyze smoke movement primarily as adopted from designers of ventilation systems. Mr. Keough mentioned that in Australia buildings 150 feet high or greater must be pressurized to 0.1 inch of water with 10% of escape doors open. Dr. Becher described experiments with rats in CIB Report 68/44(D). It was concluded that fatalities were due to carbon monoxide generally, except that irritation was the primary cause in the case of burning PVC materials. It was remarked that guinea pigs probably would be better, especially since coughing could be observed. Dr. van Elteren remarked that $HC\ell$ was produced earlier than CO in PVC burning and may be the initial hazard. He also reported on a forthcoming meeting in Eindhoven in which smoke movement in buildings would be discussed; the meeting to take place in approximately two weeks. In the discussion Mr. Malhotra inquired of Mr. McGuire how smoke could pass through concrete elevator shafts. The reply was that smoke can flow through brick work and masonry and that he had found that the amount passing through exterior walls was about the same as the amount passing around closed windows. Mr. Malhotra also remarked that a smoke-resistant diaphragm must surely also be fire-resistant.

Mr. McGuire noted that in Canada they considered the stack effect most important, and the wind also important whereas in England the wind was considered most important and the stack effect also important. Dr. Kawagoe talked about the "smoke load" in buildings and remarked that in the design of buildings the smoke load must be taken into account in the same way that an allowable structural load is taken into account.

## 2.3 Group 3 (Fires in Single Compartments) and Discussion

Mr. Heselden reported the work of Group 3 in three parts: (1) results from tests of the first phase and its analysis; (2) the available data from the second phase, and (3) contributions on other fire tests. In regard to the first phase all tests are completed and analysis of the data from the weight participating labs was partly completed. For ventilation-limited burning the shape of the compartment had the greatest effect on $R/A\sqrt{H}$ and its maximum effect was approximately 30%. Almost all of the effect of scale was covered by the factor $A\sqrt{H}$. Even with the 441 shape with full open windows there was some similarity to a ventilation-limited fire and in this case the amount of fuel did not influence the rate of burning although the value of $R/A\sqrt{H}$ was about 3 instead of 6 $kg/m^{5/2}$. For other shapes and larger windows, analysis is more difficult and incomplete and it is not possible to consider only fire load density appropriate to furnishings. Temperature and radiation data are only partially analyzed and the effect of insulation is still unknown. The data is on punched paper tape and it is available upon request. It is the intent to draft a report as a CIB publication with special emphasis on the way in which the results can be applied to real situations, i.e. where stick spacing, stick thickness, etc. have little or no effect so that the results can be considered applicable to furniture. If effects which cause less than, say 20%, variation in duration of flaming, are omitted, the presentation of data becomes simplified. On the second phase of the program - growth of fires in compartments to flashover - five laboratories have started testing and only the Fire Research Station has completed its series of 32 tests. So far some differences have been noted, but these can be accounted for. For example, the position of ignition and possibly also the amount of fire load has as much effect as the presence of a hardboard lining on the wall. Based on the completed JFRO test series, the effect of the lining is important if ignition is at the corner, but has practically no effect if ignition is at the center. The fire growth problem is very complex. However, there is no reason to reduce the emphasis on other factors and the experimental design is to continue as planned. The results of the preliminary series of eight tests at NBS were compared with those at the UK, and found to be approximately 20% longer in the characteristic

times. However, they were quite consistent with the results from Australia and Karlsruhe. With regard to the third topic, some work has been going on outside the CIB program to study the effect of the position of the lining (in Holland and in France) and the effect of ventilation opening (in the USA). So far no effects of scale have been studied although there is reason to believe that there may be some. In a discussion that followed Col. Cabret reported that a difference in the ranking of materials used for wall linings between full scale and model tests was observed. He remarked that dimensional analysis should be made. Prof. Herpol reiterated that dimensional analysis should be attempted even if some factors are ignored. There were some remarks to the effect that dimensional analysis breaks down because of the conflicting requirements involved in radiation scaling versus conduction and convection scaling. There was some discussion as to the importance of the thermal conductivity of the wall in the case of earlier fire growth. Prof. Herpol indicated that temperatures in furnaces and in compartments are very similar even though the fire load is changed greatly.

Jack Young from the Factory Mutual Research Corporation offered to participate in the Fires in Compartments program and Mr. Heselden suggested that since scale effects were not part of the program this would be a very profitable area to investigate. It was decided that Factory Mutual would contact NBS with regard to setting up a program for repeating tests on the one meter scale and then extending the testing to larger scale.

Additional details from the data received in the first phase program were reported in the original group discussion. It was found that the use of floor area permitted inclusion of data from both the half meter and one meter scale sizes to be plotted together. It was also found that the effect of spacing of wood in a crib from 2 cm to 6 cm had only a 5% effect; doubling the fire load from 20 to 40 $kg/m^2$ had only a 6% effect; and changing the shape of the compartment 121 versus 221 had the largest effect. These values were obtained from a multiple regression analysis in which the independent variables of scale, fire load density, fuel spacing, fuel thickness, compartment shape were examined with respect to the dependent variable $R/A\sqrt{H}$. The standard deviations of the residuals was about 12% for $R/A\sqrt{H}$, less than 12% for the temperature; about 24% for the equivalent window radiation, and 34% for the time to reach 80% of the initial weight. It was found that the equivalent window radiation increased from the 221 shape to the 441 shape while the temperature decreased. This is because burning proceeds from the front and sides whereas the thermocouple indicating temperature is not a very good measure of the overall temperature condition.

Table 1 shows the % effect produced by each of the major factors examined for the ventilation limited (1/4 open window) and for the fully open window conditions. More detailed data and analysis are given in J. F. R. O. Internal Notes 319 and 320.

Table 1

Percent Effect of Major Factors for 1/4 Open and Full Open Window Conditions Fully Developed Compartment Fires

| Factor | Rate of Burning Parameter $R/A\sqrt{H}$ | | Temperature Near Ceiling $\theta_c$ | | Equivalent Radiation Intensity $I_o/\phi$ | | Time to 80% of Initial Weight $t_{80}$ | |
|---|---|---|---|---|---|---|---|---|
| | 1/4 Window Opening | Full Window Opening | 1/4 Window Opening | Full Window Opening | 1/4 Window Opening | Full Window Opening | 1/4 Window Opening | Full Window Opening |
| SCALE | -15 | | 25 | | 35 | 12 | - 22 | 37 |
| FIRE LOAD DENSITY | - 6 | | - 3 | | 14 | | 40 | 19 |
| FUEL SPACING (relative) | 5 | | -11 | -20 | 15 | | - 40 | -55 |
| FUEL THICKNESS | | | - 5 | | | | - 26 | -28 |
| COMPARTMENT -WIDTH/HEIGHT | 35 | | 5 | -19 | 35 | | - 35 | -28 |
| -DEPTH/HEIGHT | | | -20 | | | | +185 | 75 |
| RESIDUAL ERROR | 12 | | 5 | 11 | 21 | 12 | 34 | 20 |

With regard to the overall spread time, $T_3$, in the second phase program, it appears that the most significant effect is due to stick spacing, i.e. bulk density. The position of ignition, the fuel height, whether the crib is continuous or separated and whether the box is lined or unlined are all affected by interactions. (See Table 2.)

Table 2

Effect of Major Factors on Overall Spread Time ($T_3$)
Growth to Flashover Compartment Fires

| Factor | Level 1 | Level 2 | Change in $T_3$, min |
|---|---|---|---|
| SHAPE | 121 | 211 | -1.3 |
| IGNITION POSITION | Corner | Center | -7.7* |
| FUEL HEIGHT, cm | 16 | 32 | +3.5* |
| VENTILATION | 1/4 | 1 | +0.6 |
| BULK DENSITY | 2.1 | 2.3 | -5.8 |
| CONTINUITY | Continuous | Separated | +8.3* |
| LINING | Unlined | Lined | -6.8* |

* Affected by interactions

Calculated $T_3$ Values (min) for Major Interactions

Interaction

Fuel Height and Continuity

| | | Continuous | Separated |
|---|---|---|---|
| Fuel Height | 16 cm | 23.1 | 27.2 |
| | 32 cm | 22.4 | 22.2 |

Ignition Position and Lining

| | Unlined | Lined |
|---|---|---|
| Ignition at Corner | 23.1 | 18.4 |
| Ignition at Center | 17.5 | 14 |

It may be interesting to examine the difference between the time at which flames reach the ceiling and the time at which all the cribs are involved. Dr. Thomas suggested that the ratio of the height of the fuel bed to the height of the room could also be quite important. It was also brought out in the discussion that humidity appears to be quite important in two ways: first by making ignition difficult and secondly by making flames spread slower. It would be advisable to state the temperature and relative humidity at the time of each experiment and to establish a certain relative humidity above which tests would not be performed. This might be 70% or 90%. A letter is to follow on uniform presentation of data on a modified data sheet.

At TNO (Holland) some work has been done outside this program which may be relevant. Tests have been conducted in a 1 m x 1 m x 1 m compartment with a continuous crib 80 cm square and 8 cm high using 2 cm sticks with 2 cm spacing. Ignition is forced at the right front using fiberboard saturated with kerosene. Considering three walls and the ceiling there are 16 combinations of wall and ceiling linings. To date tests have been done with wood and "Formica". Attempts with polystyrene were dropped because the testing was very difficult. Yet to be done are fiberboard and polyester. It was found that with the ceiling lined with wood, the time to flashover decreased by 4-1/2 minutes compared to no linings. With a wood finish on the walls behind the ignition source the time to flashover decreased by 6 minutes. With the ceiling and wall behind the ignition source both lined with wood the time to flashover decreased by 10 minutes. It was concluded that the results are additive. When "Formica" is used there is an increase of two minutes in each case. The weight of the crib was 20 kg.

Dr. Thomas reported on the JFRO fire propagation test. He noted that oxygen concentration in the exhaust could be related to weight loss, whereas very little temperature vs. weight correlation had been noted because of the time lag to heat the parts of the chimney. The reference he quoted was Fire Research Note 709 written by Hinkley. Using a fast burning fiberboard specimen the oxygen concentration dropped to 0%. He noted that CO and $CO_2$ could also possibly be used. In principle the oxygen concentration would be expected to give a better correlation with heat release than the temperature in the stack. Mr. Traverse remarked that weight loss was not directly related to heat generated but that heat potential per gram of oxygen was more constant than calories per gram of fuel.

With regard to the general question of what to do with information obtained in the CIB cooperative programs Mr. Lawson stated that the publication of raw data from noncombustible boxes with cribs is not of

too much value and he would like to see a publication stating what the results mean in terms of real occupancy. Where data is not related to stick size, stick spacing, etc. it should be possible to come to general conclusions which would be applicable to furnished rooms* or to rooms containing stored combustibles. It occurred to me that each lab in the second phase study could allow one or more of its experiments with a hardboard lined box to go to completion and in this way to obtain data on rate of burning, radiation, etc. under fully developed fire conditions and this would bridge the gap between the first phase, which involved the fully developed stage in a noncombustible compartment, and the second stage, which is examining the effect of wall linings in the earlier growth stages only. It may also be possible to add tests with fiberboard and gypsum board linings to complete the test series.

*Results of some tests conducted in a large-scale compartment indicate that the rates of burning of furniture fires were close to those of wood crib fires having the same fire load/ventilation area (J. F. R. O. Fire Research Note No. 718, "Fully-Developed Fires with Furniture in a Compartment", by C. R. Theobald and A. J. M. Heselden, July 1968).

## 3. DISCUSSION OF SELECTED PAPERS

Paper No. 66/37 (CA) "Fire Resistance Tests on Circular Pivoted Type Automatic Fire Damper, on a Rectangular Pivoted Type Automatic Fire Damper, and on a Rectangular Louvered Type Automatic Fire Damper" was presented by Mr. Keough. He illustrated the improvement obtained by means of a double bladed damper. Mr. Malhotra noted the need for a damper which could serve also as a smoke barrier, particularly for cool smoke. Mr. Keough remarked that a technique does exist for measurement of "room temperature smoke" using free air flow and making upstream pressure measurements. A new Australian standard requires a smoke detector for actuation rather than the customary fusible link or temperature-actuated detector. In reply to Prof. Herpol's question as to whether the furnace pressure was elevated, Mr. Keough replied that the furnace was not pressurized but did in effect operate under a very slight positive pressure, approximately .001 inches of water.

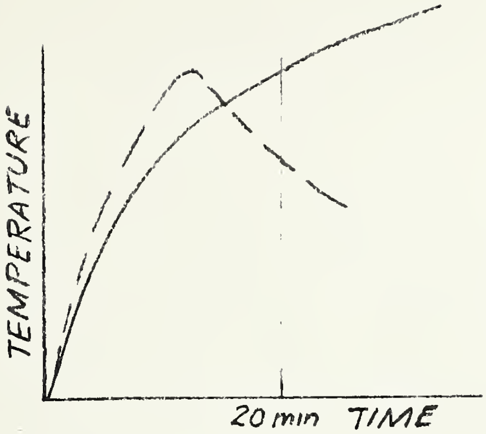
Paper No. 67/9 (DK) "Fire Requirements in Connection with Heating, Plumbing and Ventilation of Dwellings" was presented by Dr. Becher. Where a duct pierces a fire-rated wall, Dr. Becher estimated that a duct limitation of 5,000 $cm^2$ cross section area would be required. Mr. Malhotra remarked that a duct area of 100 sq in/100 sq ft of floor area (i.e. approximately 1%) is customarily permitted. A PVC vent or waste pipe up to 10 cm in diameter will prevent fire transmission, but must be enclosed in a fire-resistant shaft. Mr. Keough remarked that NFPA 90A permits up to 29 sq in of duct (piercing a fire barrier) without the requirement of a damper. Mr. Lawson wondered whether the use of ureaformaldehyde foam to act as a duct closure at the fire barrier couldn't be an inexpensive way for obtaining a fairly good closure.

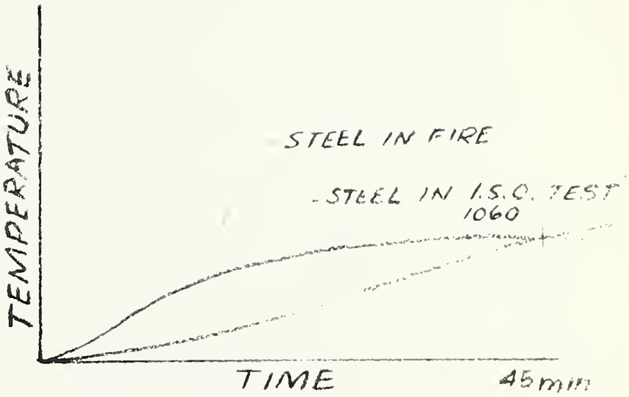
Paper No. 67/31 (UK) "Fire Research Note No. 662 - Maximum Sizes for Fire Resisting Doors and Shutters" was presented by Mr. Malhotra. It was mentioned that water cooling on fire doors was effective. Mr. Keough noted that in Australia, 95% of the fire doors are asbestos insulated with wood veneer and only 5% are steel, compared to a much higher percentage of steel doors in the UK.

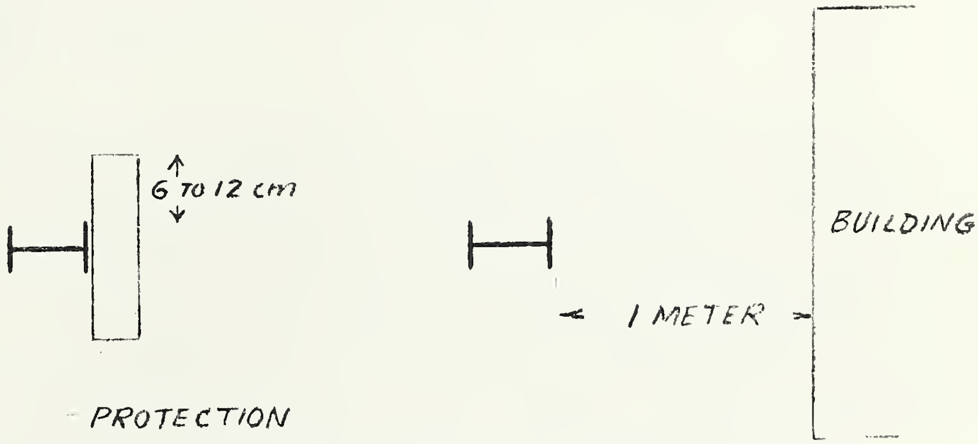
Paper No. 67/35 (UK) "Fire Research Note No. 678 - Fire in the Motor Car - Results of Tests on the Propagation of Fire in Parked Cars" was presented by Mr. Butcher. He stated that for fire loads up to 10 $kg/m^2$ (2 $lb/ft^2$), steel members need not be protected according to previous (BISF) work. Since the fire loads in car parks was measured as 17 $kg/m^2$ (3.5 $lb/ft^2$) the question arose as to whether fire would spread and involve all the cars. From the results of the tests reported,

the answer is "no". For above ground open sided garages, British authorities are prepared to relax fire resistance requirements, i.e. to permit unprotected steel columns. Mr. Becker noted that a fully loaded truck in a tunnel caught fire in Germany and caused extensive spalling of reinforced concrete. Mr. Keough noted that of 70 cars burned during the Tasmanian bush fire not one fuel tank rupture was experienced. In reply to a question Mr. Butcher stated that flames extended along the ceiling over adjacent cars but did not extend outside the building. Col. Le Puloc'h noted that in an actual fire in an underground parking garage in France, the polyethylene tube between the fuel tank and the carburetor was melted due to the fire permitting gas to flow out and burn on the ground. However, there was no fuel tank rupture.

Paper 66/35 (UK) "Fire Research Technical Paper No. 15 - The Temperature Attained by Steel in Building Fires" was presented by Mr. Butcher. In addition to the results presented in the paper, Mr. Butcher stated that later tests were conducted to examine whether furnishings would burn differently from wood cribs. In the furniture fires, temperature fell into the same pattern as would be predicted from the wood crib tests. With 7.5 $kg/m^2$ (1.5 psf) of gasoline and kerosene, the air and unprotected steel temperatures were much higher than with wood cribs. A critical steel temperature of 600 $^{o}C$ was almost reached but its duration was very short. Mr. Becker commented on the work of Boue in Hamburg for the German Committee of Steel Construction. In Hamburg, they did not use wood cribs but followed the standard time-temperature curve in ISO 1060. It was found that by increasing the spacing between the building and the external unprotected columns by 1 meter the temperature level was reduced by 100 $^{o}C$ which was considered adequate. Mr. Stanke stated that kerosene fires were not realistic principally because of the difference in the smoke produced. Mr. Witteveen inquired whether it was possible to relate these tests to ISO 1060 fire endurance tests. Mr. Butcher replied "yes", as given in the Steel Symposium Paper No. 4. However, he sketched the following temperature-time diagrams to indicate differences in the tests.



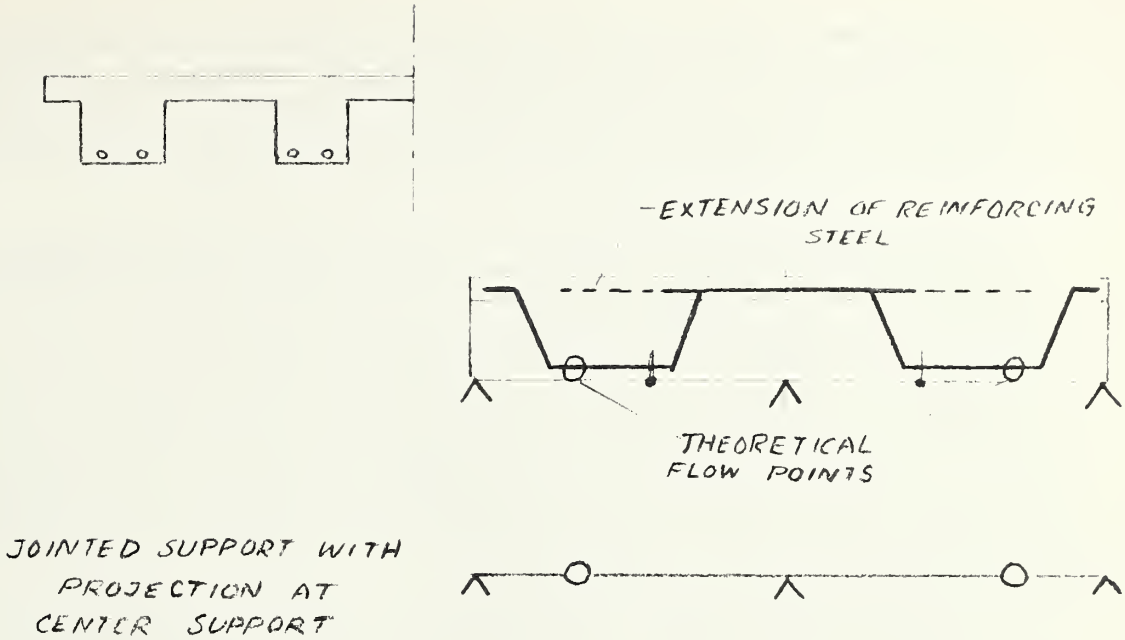

GERMAN REQUIREMENTS

The one meter offset described by Mr. Becker in the German requirements is sketched also. With regard to the use of 550 $^{o}$C as a critical temperature Mr. Keough noted that a temperature differential over the cross-section of a steel member may cause appreciable differential expansion and therefore the 550 $^{o}$C temperature may be too high. Mr. Witteveen commented on the other hand that unequal heating is not too important since on the basis of plastic design differential expansion will affect the stability of the entire building but would not cause structural collapse; thus, stability requirements are the

more conservative. Prof. Herpol disagreed in the case of columns which are critical because a small deformation in a compressively loaded column may, in fact, produce collapse. He agreed that unequal heating is not too important in the case of horizontal beams.

Paper No. 68/43 (J) "Research on the Fire Resistance of Steel Beams" was presented by Dr. Kawagoe. In this paper a deflection of L/1000 in five minutes was considered the failure criterion. Mr. Malhotra inquired as to the reason for slight negative deflections in some tests. This may have been due to possible errors, according to Dr. Kawagoe. It was also inquired whether the relation in figure 5 (between load and thermal transfer) could have been due to the formation of cracks in the insulation. Prof. Herpol remarked that in figure 4 the stress/yield point temperature tendency might be exploited for economic purposes, i.e. one may be able to use unprotected steel members where a lower design stress is used. The question came up as to whether moisture content could be the explanation of the results in figure 5, inasmuch as the endotherm at 100 °C varies considerably in duration. Durisol is a trade name for a wood/cement slab.

Paper No. 66/36 (I) "Interpretazione Della Resistenza Alfuoco Mediante il Calcolo a Rottura" (Understanding Fire Endurance Through Load Failure Calculations) was presented by Mr. Malhotra. He translated salto-termico as a heat jump, but it was not entirely clear what the author meant. Col. Cabret mentioned that in actual fires deformations occur and thermal insulation is affected in sudden and unpredictable ways which are not amenable to calculation. Mr. Malhotra replied that the properties of steel were well known, but that the materials used for protection were much more complex, and usually introduce effects due to moisture. Mr. Vandevelde described the electrical analog developed in Belgium for non-steady state heat transfer using a step-by-step resistor analog where resistors are used to simulate both thermal conductivity and heat capacity (c.f. papers by Liebmann). Mr. Becker remarked that a concrete ribbed ceiling was tested in Berlin in 1964 and that a displacement of the static system took place after failure. Since some reserve strength was found, the calculations should be considered on the conservative (safe) side. He illustrated how extension of reinforcing steel could increase the fire endurance period from approximately 45 minutes to over 120 minutes.




Mr. Keough mentioned that an article published by Mr. P. E. Ellen (Constructional Review, 38 (4), 17-25, April 1965; 38 (5), 26-30, May 1965; 38 (10), 19-25 Oct. 1965, Sydney) contained a proposal to use lightweight prestressed concrete with negative reinforcement. No account was taken of fire performance and large deflections were permitted in the case of fire. Mr. Witteveen commented that with prefabricated units using static design methods, there is no redistribution of loads as in restrained (i.e. continuous) structures, and a single failure of one element may conceivably cause catastrophic failure. Col. Cabret remarked that fire is only a part of the overall problem of which structural stability is probably the most important. Mr. Keough noted that building regulations have usually been very conservative, e.g. the use of four-hour constructions where fire loads equivalent to only two hours are found. Mr. Malhotra stated that the normal factor of safety of about 2 could be lowered to 1.5 or 1.6 with more precision in the measurement. Mr. Bellisson stated that increasing the static safety coefficient does not necessarily increase fire performance.

Paper No. 68/33 (USA) "NBS Report No. 9698 - Techniques for the Survey and Evaluation of Live Floor Loads and Fire Loads in Modern Office Buildings" was presented by D. Gross. Mr. Becker noted that a test method is currently under development in Germany to measure the contribution of heat and the effect of thickness and specific surface

of combustibles. This work was being done cooperatively with Belgium and Holland. Dr. Odeen noted that in order to calculate the temperature rise due to fire, it is proper to use the load per unit total area, i.e. floors, walls and ceiling, and this type of calculation is included in the Swedish regulations.

Paper No. 68/41 (J) "Estimation of Fire Temperature Curves in Rooms" was presented by Dr. Kawagoe. This paper was an extension and improvement over a previous paper with the same title. It includes a computer program for calculation of the temperature-time curve. Dr. Kawagoe noted that the assumed temperature dropoff at a uniform rate was too conservative and that in any case this had very little effect on the temperature of an internal member. He also stated that (a) the total area was very nearly proportional to the floor area, and (b) the floor factor was very nearly proportional to the floor area. He himself stated that the use (in the report) of q = 2575 calories per gram in all cases was questionable.

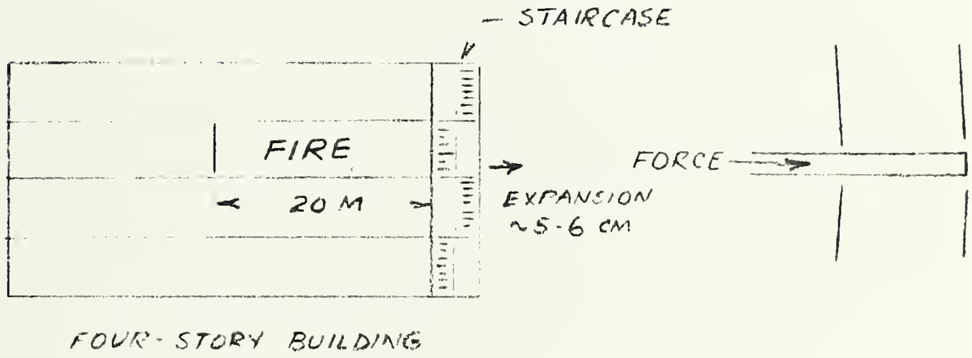
Paper No. 68/11 (USA) "NBS Report No. 9369 - Report on Fire Tests on Two SCR Brick Wall Columns" was presented by Dr. Robertson. Considerable interest was noted in the experimental finding that collapse under load occurred on one specimen 1-3/4 hours after the 2-hour fire exposure was terminated. Since European practice (c.f. British Standard BS 476) is to re-apply the load 48 hours after the heating period, whereas current American practice (ASTM E-119) does not require any further load application, direct comparisons of test results are probably not possible.

Paper No. 68/34 (USA) "Research and Development Laboratories of the Portland Cement Association - Research Department Bulletin 212 - Fire Endurance of Simply Supported Prestressed Concrete Slabs" was presented by Dr. Robertson. Mr. Becker questioned the separation between curves labelled "1-, 2- and 3-inch cover" in figure 4 and noted that times would be expected to scale as a power function of distance. Specifically how can there be a greater distance between the 1- and 2-inch cover lines compared to the 2- and 3-inch cover lines? Since the temperature curves were not shown below 300 F it was not clear as to the duration of the moisture endotherm.

Paper No. 68/37 (S) "Fire Resistance and Prestressed Concrete Double-T Units" was presented by Dr. Odeen. He used an IBM 7090 routine (designated D2*AT F RKS3) to calculate temperature as a function of time. This computer routine is available upon request, but subject to approval of the sponsor (a concrete beam manufacturer).

Dr. Kawagoe pointed out that in figure 20 the value of alpha ($\alpha$) was very low. In an actual fire, $\alpha$ is expected to be greater than 200 kcal/m$^2$ hr $^\circ$C. According to Dr. Kawagoe, this is more important than whether the coefficient should be or is greater for the sides or bottom of the slab, as some delegates inferred from the data shown.

Paper No. 68/43 (J) "Behavior of End Restrained Concrete Member in Fire" was presented by Dr. Kawagoe. A discussion followed on the meaning of continuity and fixed and variable restraint. Mr. Lawson threw out the following question: If restraining forces and analyses are complete, are fire tests indeed necessary? Dr. Odeen stated that in the future fire tests will provide information as to expansion, deformation and forces so that an analysis can be made of the static structure in fire. Col. Cabret stated that tests would always be indispensable. Dr. Kawagoe illustrated an interesting effect observed in a four-story reinforced concrete building, in which a section 20 meters long and 9 meters high was involved in a fire. The fire load was 50 kg/m$^2$ (10 lb/ft$^2$). The burning produced an expansion of about 5 to 6 cm in a floor slab. This moved out the vertical end wall and destroyed the integrity of a staircase.




He noted that structural behavior of a complete building in fire is very different from that of a single element in a fire test. Mr. Becker noted that if the floor slab had a lower fire endurance, then this would not have occurred. Col. Cabret stated that in Europe expansion joints would have allowed for such expansion, but Dr. Kawagoe noted that this was not possible in Japan because of the requirements of earthquake design.

## 4. VISIT TO ASBESTOS FACTORY

A visit was made to the factory of Cape Universal Building Products, Ltd. at Uxbridge. This plant produces Asbestolux - a fire protective board. It was stated that this was not an asbestos-cement board, but a lime-silica board consisting of long-strand amosite asbestos fibers bonded together with silica in a steam autoclave. Lime and diatomaceous earth are also used. We were received by Mr. R. Zukowski who was in charge of research and we visited their fire test furnace consisting of a 1-1/2 meter cubical furnace and also the Asbestolux automated production line. We also visited their research building to see demonstrations of Young's modulus measurements at elevated temperatures, differential thermal analysis and measurements of dilatometry and thermal expansion. A description of the fire protection research at Cape Universal is given in Appendix C. This company is the largest asbestos sheet manufacturer in the United Kingdom and its closest sales representatives are the North American Asbestos Company in Montreal and Winnipeg, Canada.

## 5. EXPERIMENTAL FIRE IN A LARGE SCALE COMPARTMENT

An experiment was performed in a compartment 7.7 m x 7.5 m x 3.05 m high with window openings on each of the long walls which face North and South respectively. This is the same building described in detail in Fire Research Technical Paper No. 15, and the single large compartment was formed by removing the wall which separates the North and South compartments. A fire load consisting of furniture distributed at 25 $kg/m^2$ of floor area (5 $lb/ft^2$) was arranged as realistically as possible to simulate a furnished apartment. The purpose of this test was to determine the behavior of a fire in a compartment with windows on two opposite walls so that there could be a through draft. All previous tests contained windows on one side only. Ignition was by means of a pan of gasoline under a wood crib placed under a table. Additional details of the fire experiment, including the locations of protected and bare steel columns are given in Appendix D. At the start of the test the wind was generally southwesterly (SSW 10 km/hr 2 hours before the test), but this switched to westerly with considerable variation and the wind probably had no appreciable effect on the test result. Flaming occurred principally from the center towards the north part of the compartment and at one point appeared to be dying down. Window openings were glazed initially except for one foot open at the top, but the panes were intentionally knocked out each time a crack developed (to avoid possible injury to observers). Eventually, with the involvement of a tall wooden cupboard, the entire compartment became involved and complete burnout of the combustibles resulted. I doubt whether any significant amount of combustibles remained after the test, the duration of which was approximately 45 minutes. One interesting aspect of the test was a steel file cabinet (not fire-rated) which contained papers. Flames were observed issuing from the cracks in the drawers and very little of the contents probably remained following the test. Preliminary data were as follows: wind gusts up to 17 ft per second were noted; flashover occurred about 28 minutes; maximum temperatures on columns were as follows: the north exterior unprotected columns: 200 °C, the south exterior unprotected column: 180 °C, the interior concrete covered column: 140 °C, mineral wool covered column: 140 °C, unprotected steel column: 800 °C and wood protected column: 380 °C. Maximum temperatures were reached between 40 and 50 minutes.

## 6. FINAL DISCUSSIONS

With regard to current research problems, there were five principle subdivisions:

A. Work Already Concluded - It was decided to prepare a draft report on the cooperative program on fully developed fires. This will be circulated among the participating countries for discussion and a final draft will be prepared for publication as a CIB paper. In the second phase, involving the growth of fires to flashover, it was decided to continue as planned. Factory Mutual Laboratories offered to examine the effect of scale and they will be added to those already participating. It was agreed that a progress report will be drafted in time for the next meeting. Col. Cabret wondered whether we should include results from full scale tests to compare with the model results. Mr. Lawson replied that JFRO often makes a model test at the time when a full scale test is being performed, for just such a comparison.

B. Extension of the Work of CIB Commission W.14 to New Areas (Fire Fighting, Detectors and Sprinklers, Economics, etc) - Col. Cabret suggested that the activities be limited to the effects of fire on the building, and on building materials. Mr. Becker noted that in Germany, unlike the UK, the industrial and administrative portions are separated from the building fire interests, and he suggested that each country should investigate to what extent an extension of its work (such as by increased delegation) into these other fields would be possible. Col. Cabret noted that he was opposed in principal to extensions of the work of this committee. However, he noted that if the work were to be extended to other areas, additional representatives from fire brigades, the home office, etc. would be required.

C. Relations with ISO, CTIF, etc. - It was noted that CIB performs basic research which can lead to the establishment of standard test methods in ISO, and CIB can advise ISO as to their use. Mr. Bellisson noted that ISO meetings sometimes become involved in practical questions which can be aided by CIB advice and information. Mr. Lawson remarked that it would be well for CIB to send copies of its reports to ISO for their information. Mr. Becker requested that the heads of delegations prepare a statement indicating to what extent the CIB work is and can be distributed and used by insurance, economic and building code officials. Col. Cabret felt that such items are best left to the individual countries.

D. <u>CIB Approach to Problems, Cooperation and Resources</u> - Mr. Lawson wondered whether the cooperative tests should only involve small tasks or whether individual laboratories should report on their own work without duplication. Col. Cabret stated that the economic problems in each laboratory limited the extent of cooperative work to relatively small tasks. It was decided to continue with a review of research consisting of approximately 50 words describing a project, the name of the responsible individual, and the expected completion date, and that the next edition should have as a target date, August 1969.

E. <u>New Cooperative Programs</u> - Mr. Witteveen mentioned the construction of a 1 m x 1 m x 1 m furnace in Holland to perform fire tests to examine the effects of restraint on fire performance. Mr. Lawson spoke about the advantages of interchange of research workers from other countries where large tests would be performed. Dr. Robertson mentioned the very successful Research Associate program at NBS. Mr. Van Elteren noted that a plastics group from the UK would be participating in upcoming plastics tests in Holland. Mr. Lawson made a plea that CIB be informed of any large scale tests to be performed and to send invitations for guest workers to participate. A discussion developed concerning the availability and proper distribution of CIB reports especially those containing a designation of "restricted" information. Each country described its limitation on the distribution of its reports. In the UK a yellow cover indicates work of a committee and this report is not to be circulated. A green cover indicates preliminary work which has not yet been published but can be discussed. It was stated that CIB reports should: (1) not appear on lists available to libraries; (2) not be referenced in publications; (3) not be used to create a demand for the report; and (4) not be shown to industrial firms who may be in competition.

The final item of the meeting was the selection of France as the site for the next CIB meeting in 1970, tentatively May or June.

# APPENDIX A

## LIST OF DELEGATES

| | | |
|---|---|---|
| AUSTRALIA | Mr. J. Keough | Commonwealth Experimental Building Station<br>Chatswood, New South Wales |
| BELGIUM | Prof. G. Herpol<br>Mr. Vandevelde | Laboratoire pour l'Emploides Combustibles<br>University of Ghent<br>Ghent |
| CANADA | Mr. J. H. McGuire | Fire Section<br>Division of Building Research<br>National Research Council<br>Ottawa |
| DENMARK | Dr. P. Becher<br>Mr. J. Holst | Danish National Institute of Building Research Laboratories<br>7 Lundtoftevej, Lyngby |
| | Mr. H. Lundsgaard | Danish Fire Protection Association |
| FRANCE | Col. A. Cabret | Centre Scientifique et Technique du Batiment<br>4 Avenue du Recteur Poincare<br>Paris XVI |
| | Mr. M. Bellisson | Centre Scientifique et Technique du Batiment<br>Champs-sur-Marne |
| | Mr. M. R. Traverse<br>Cdt. R. Haure | Bureau Technique et de l'Equipment du Service National de la Protection Civile<br>Ministere de l'Interieur<br>60 Boulevard Gouvion Saint-Cyr<br>Paris 17e |
| | Lt. Col. Le Puloc'h | Paris Fire Brigade |

| | | |
|---|---|---|
| GERMANY | Mr. W. Becker | Badischen Anilin & Soda-Fabrik AG<br>Ludwigshafen |
| | Dr. W. Westhoff | Staatliches Materialprufungsamt Nordheim - Westfalen<br>Dortmund - Aplerbeck |
| | Mr. Dreyer | Institut fur Baustaffkunde und Stahlebetonbau<br>Technische Hochschule Braunschweig<br>Beethovenstrasse 52<br>Braunschweig |
| | Dr. P. Seeger | |
| | Mr. S. Stanke | Bundesanstalt fur Materialprufung<br>Unter den Eichen 87<br>Berlin |
| HOLLAND | Dr. J. F. van Elteren | Brandveiligheidsinstitut (Institute for Fire Prevention)<br>T.N.O. (Netherlands Organization for Applied Scientific Research)<br>5, Lange Kleiweg, Rijswijk (P.O. Box 49, Delft) |
| | Mr. J. Witteveen | Instituut T.N.O. voor Bouwmaterialen en Bouwconstructies<br>5, Lange Kleiweg, Rijswijk |
| | Mr. H. Zorgman | |
| JAPAN | Dr. K. Kawagoe | Building Research Institute<br>4-Chome Hyakunin-Cho, Shinjuka-Ku,<br>Tokyo |
| | Dr. M. Inui | Same as above, on leave 1 year with:<br>Building Research Station<br>Garston, Watford, Herts |

| | | |
|---|---|---|
| NORWAY | Mr. H. A. Bakke | Fire Research Laboratory<br>Technical University of Norway<br>Trondheim |
| SWEDEN | Mr. K. Odeen | Fire Engineering Laboratory<br>National Swedish Institute for Materials Testing<br>Stockholm |
| UNITED KINGDOM | Mr. D. I. Lawson<br>Mr. R. G. Silversides<br>Dr. D. J. Rasbash<br>Dr. P. H. Thomas<br>Mr. E. G. Butcher<br>Mr. H. L. Malhotra<br>Mr. J. F. Fry<br>Mr. A. J. M. Heselden | Fire Research Station<br>Melrose Avenue<br>Boreham Wood, Herts |
| UNITED STATES | Dr. A. F. Robertson | Office of Fire Research and Safety<br>National Bureau of Standards<br>Washington, D. C. |
| | Mr. D. Gross | Fire Research Section<br>National Bureau of Standards<br>Washington, D. C. |
| | Mr. J. Young | Standards-Laboratories<br>Factory Mutual Research Corporation<br>Norwood, Massachusetts |

C.I.B. Commission W.14
Programme for 8th Meeting

Sunday, September 22nd. Arrive in United Kingdom.

19.30 Informal buffet supper at the home of Mr. D. I. Lawson, (70 Deacons Hill Road, Elstree, Herts., Tel.:- 01-953-3326).

A coach will transport delegates from London. It will pick up delegates from outside the Green Park Hotel, Half Moon Street, W.1., at 18.15, and from the New Ambassadors Hotel, Upper Woburn Place, W.C.1., at 18.30.

---oOo---

Monday, September 23rd. at Fire Research Station

10.00 - 11.00
(a) Welcome by Director of Fire Research.
(b) Elect Chairman for the week's proceedings.
(c) Acceptance of record of 7th Meeting.
(d) Divide into three Groups.

11.00 - 12.30 )
14.00 - 17.00 ) Groups discuss progress since previous meeting:-

Group 1 - Fire endurance.
Group 2 - Spread of smoke and toxic gases.
Group 3 - Fires in single compartments.

---oOo---

Tuesday, September 24th. at Fire Research Station

09.30 - 12.30 Report back from Groups
14.00 - 17.00 Discussion of papers:-

CIB/CTF 66/37(CA)
" " 67/31 (UK)
" " 67/9 (DK)

---oOo---

Wednesday, September 25th.

Morning - Visit to Cape Universal Building Products, Ltd., Uxbridge. Lunch will be provided at the factory.

Afternoon - Visit to Palace of Westminster (Houses of Parliament)

A coach will transport delegates from London. It will pick up some delegates at the New Ambassadors Hotel, Upper Woburn Place, W.C.1., at 09.30 and the remainder from the Green Park Hotel, Half Moon Street, W.1., at 09.45. It will also return delegates to their starting points at the end of the day.

---oOo---

Thursday, September 26th. at Fire Research Station

09.30 - 12.30 Discussion of papers:-

CIB/CTF 66/35(UK)
" " 66/36(I)
" " 67/35(UK)

14.00 - 17.00 Discussion of papers:-

CIB/CTF 68/5(I)
" " 68/33(USA)
" " 68/34(USA)

Evening - Buffet supper as guests of the Fire Offices' Committee at Aldermary House, Queen Street, London, E.C.4.

---oOo---

Friday, September 27th. at Fire Research Station

09.30 - 12.30 Discussion:-

(a) Current problems on which research is required.
(b) Future activities of Commission.

14.00 - 17.00

(a) Experimental fire in large-scale compartment.
(b) Other business.

---oOo---

Notes:- 1. Discussions

During the discussion periods it is proposed that the delegate introducing a paper shall speak for 10 - 15 minutes, allowing 30 - 35 minutes for general discussion (i.e. total time for each paper - 45 minutes)

2. Travel arrangements

Coach transport will be provided for the informal gathering on Sunday, September, 22nd, and for the visits on Wednesday, September 25th. On other occasions delegates will need to make their own arrangements.

For journeys to the Fire Research Station it will be most convenient to travel by train from St. Pancras Station (see card attached).

# APPENDIX C

## FIRE PROTECTION RESEARCH AT C.U.B.P.

As a Company supplying an International market with materials for structural fire protection, we are concerned not only with testing elements of building structures such as partitions, walls, floors, columns etc., but also in the materials used in these constructions. In order to conduct a balanced research programme, our facilities include a fire test furnace and number of specialised techniques for materials research such as Dilatometry, Determination of Elasticity and Strength at Elevated Temperatures and Differential Thermal Analysis for investigating phases of thermal decomposition.

The fire test furnace, which is approximately 1.5 meter cube, has been developed over a period of years to give results which correlate closely with those of Joint Fire Research Station. The heating is provided by two paraffin burners on one side of the furnace, positioned in such a way as to give uniform temperature conditions for three types of structural testing: partitions/walls, ceilings/floors/beams and columns. The shape of the furnace, positioning of the hot gases exhaust and chimney design have all been studied to arrive at this condition. The euipment is also used for experimental work to check performance of new formulations, competitive products, customers constructions and for our own structural fire protection programme.

Constant search is also being carried out into alternative raw materials, and formulations and since this type of work is impossible to carry out using full size board specimens, a number of Laboratroy techniques have been developed to permit detailed study on small scale.

Thermal shrinkage at elevated temperature can be studied by Dilatometry and fully automatic apparatus which can operate on a variety of heating rates giving continuous contraction/expansion trace is used for test purposes.

Together, with this, Differential Thermal Analysis technique provides information as to the materials, composition and thermal breakdown of the specimen under test. The technique consists of heating at a controlled rate a small sample of the material under test. A thermally stable material is heated at the same time and the difference of temperature produced by exothermic or endothermic reaction in the sample is determined against the reference material.

Characteristic traces are produced by raw materials or products of reaction and the techniques is used to identify these. It is also possible to run the equipment under vacuum or in inert atmosphere when, for example, combustible products can be detected.

To obtain information on the stresses involved within the material, equipment is available to determine Tensile Strength and Modulus of Elasticity at elevated temperature. The latter technique is particularly useful as it indicated changes in Modulus of Elasticity which can be compared with DTA and Dilatometer results. The method, although already used as a research tool, is still under development and basically invloives determination of the resonant frequency of a bar of material. This information being used to calculate Youngs Modulus. The bar is vibrated at one end and the resonant frequency is determined. The input and output are fed to XY plates of an Oscilloscope displaying phase relationship visually. When the sample is taken through the heating cycle, changes in crystal structure due to thermaldecomposition, are reflected in the change of Youngs Modulus which can be determined continuously.

The range of equipment has been set up specifically to enable us to study in detail, performance of fire protective materials and structures and to investigate effects of changes in raw materials, process conditions, fixing methods etc. on fire properties. We anticipate this programme of work to lead to new and improved products for fire protection.

MINISTRY OF TECHNOLOGY AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

APPENDIX D

CIB/CTF 68/30(U.K.)

## Experimental Fire in a Large Scale Compartment

At last year's meeting delegates expressed an interest in a test designed to show the behaviour of a fire in a compartment with window openings on two opposite walls, that is in a compartment in which there could be a through draught. Mr. Lawson said that he had a suitable building at the Fire Research Station and he promised to make this available for a test.

Accordingly in connection with the meetings of C.I.B. Commission W 14 to be held at Boreham Wood in September an experiment is being planned in a compartment 7.7m x 7.5m x 3.05m high with window openings of $5.6m^2$ on each of the 7.7m long walls, which face North and South respectively.

The building is described in detail in Fire Research Technical Paper No. 15 which was circulated to C.I.B members in 1966 (CIB/CTF 66/35(U.K.)). The compartment for the experiment described here will be formed by removing the wall which separates the North and South compartments.

In the test proposed it is suggested that the fire load will be furniture distributed at 30 $Kg/m^2$ and arranged as realistically as possible to simulate a furnished apartment.

This value of fire load density is thought to be typical of housing. The Fire Research Station has already carried out a similar test with furniture (see CIB/CTF 68/24(U.K.)) in one of the separate compartments with a window in one wall and this should form a useful basis for comparison.

Initially the window openings will be glazed but the glass will be knocked out after the first few minutes of burning.

Some structural steel members will be installed, some inside and some outside the compartment and their temperatures will be recorded.

Since the date of the test must necessarily be fixed to fit in with the main programme of meetings at Boreham Wood the wind speed and direction at the time of test cannot be predicted. However, methods of inducing a draught through the compartment if the wind should be in an unfavourable direction will be investigated.

A summary of the details of the suggested experiment is given on the attached sheet.

When Mr. Lawson offered to make the facilities available for this experiment he also suggested that if any member countries wished to make measurements themselves at this test they would be welcome to do so. If any members wish to do this and wish to install any instruments on the test site for this purpose or have any suggestions they wish to make concerning the proposed experiment would they please write, as soon as possible to the Director, Fire Research Station, Boreham Wood, Hertfordshire, England quoting the reference F.1000/17/14(U) and marking the letter for the attention of Miss Margaret Law.

Details of Fire Experiment at Fire Research Station
held on Friday, 27th September, 1968 at 2:30 p.m.

Fire Compartment: 7.7m x 7.5m x 3.05m high

Windows: 5.6m$^2$ in two opposite walls (North & South walls) glazed for start of test except for 1 foot open at top.

Structural Members inside Compartment:

Seven steel columns all 20 cm x 20 cm x 52 Kg/m (8 in.x 8 in.x 35 lb/ft) Universal columns, arranged as indicated in diagram, and protected as follows:

| | |
|---|---|
| C1 | 1 in. Mineral wool slabs |
| C2 | 1 in. Plaster board |
| C3 | 1 in. Timber,held on with wire straps |
| C4 | 2 in. Concrete |
| C5,6,7 | Unprotected |

Structural Members outside Compartment

Two steel columns, each 20 cm x 20 cm x 52 Kg/m (8 in. x 8 in. x 35 lb/ft) spaced 18 in. from building.
Universal columns marked C8 and C9 on diagram and both unprotected.

Two steel beams, each 26 cm x 15 cm x 37 Kg/m (10 in. x 5-3/4 in x 25 lb/ft)

Universal beams marked B1 and B2 on diagram and both unprotected

Measurements proposed

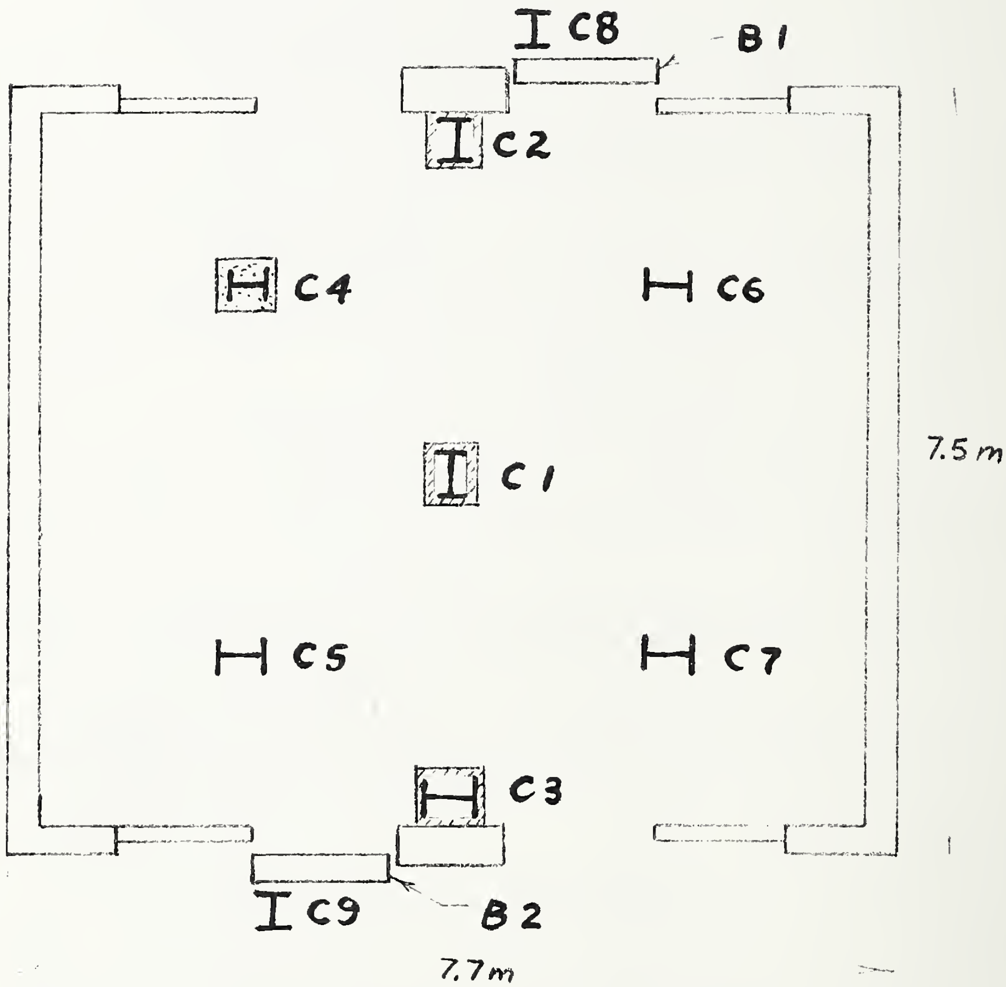
Temperature of compartment gases at 18 points.

Temperature of columns and beams, 4 points on each (28 points in all).

Radiation Intensity from window openings.

Gas analysis of atmosphere in room at 1 or 2 points.

Wind speed and direction.




Sketch Plan of Compartment showing positions of Structural Members



USCOMM-DC-NBS

DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS